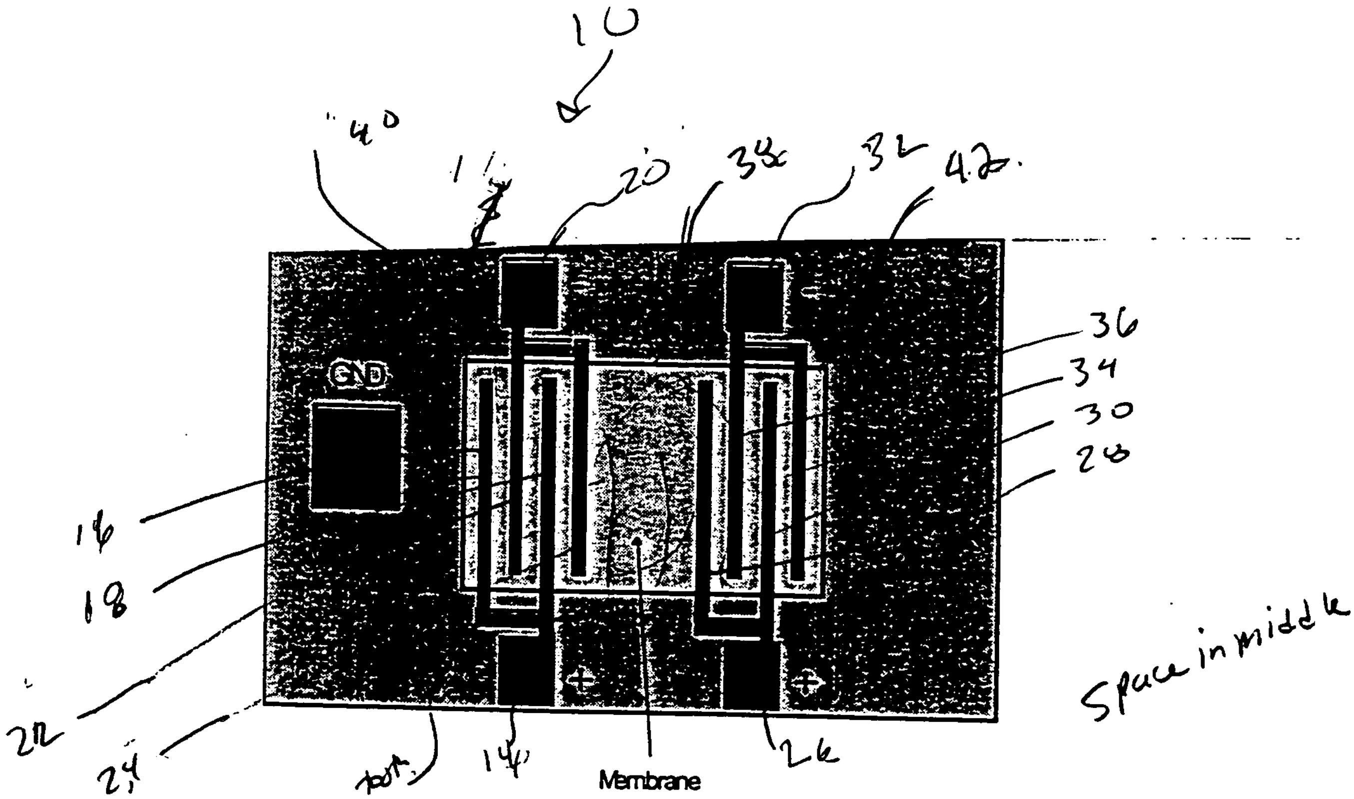


Fig. 1 (PRIOR ART)

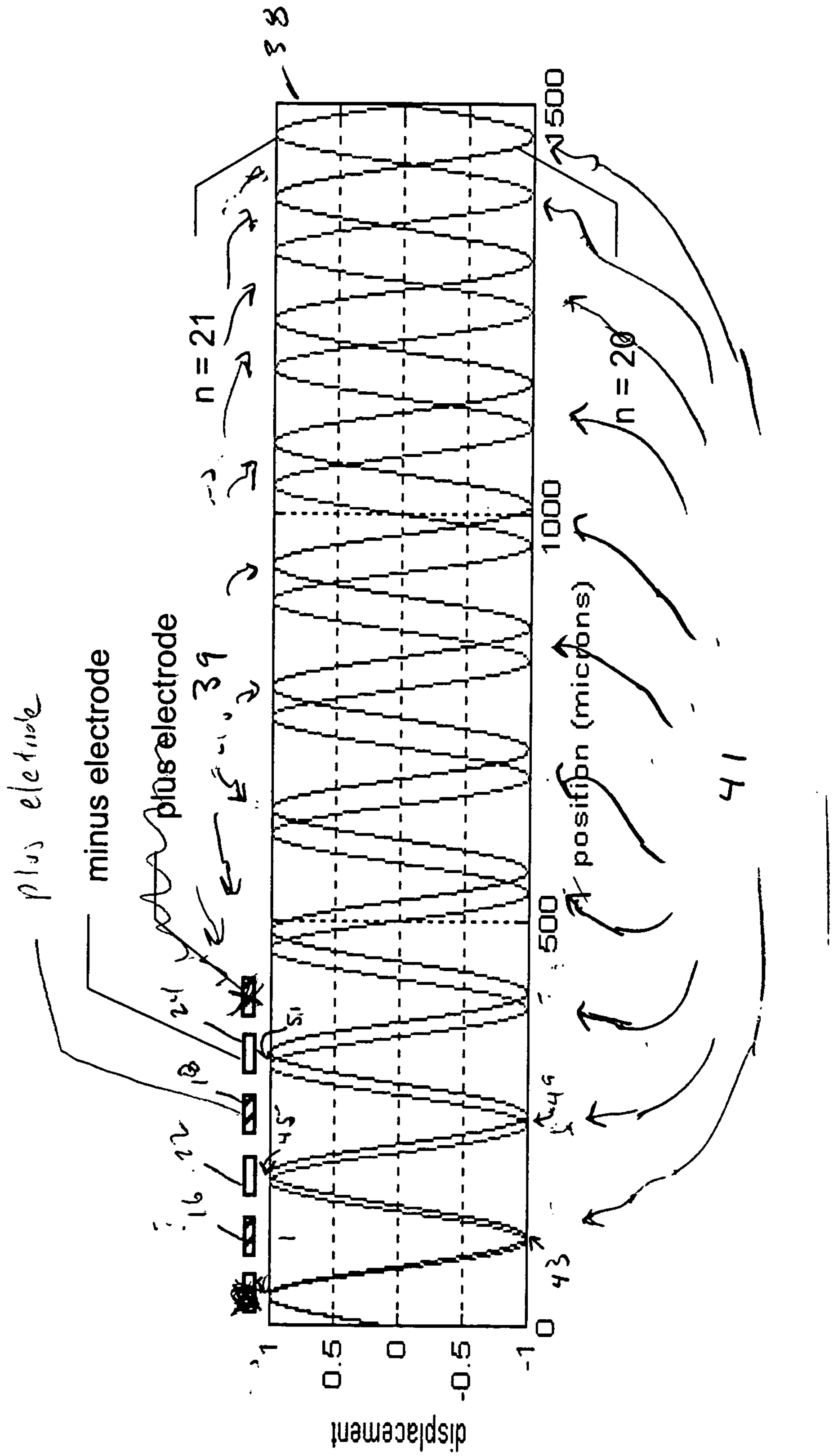


Fig. 2 (Prior Art)

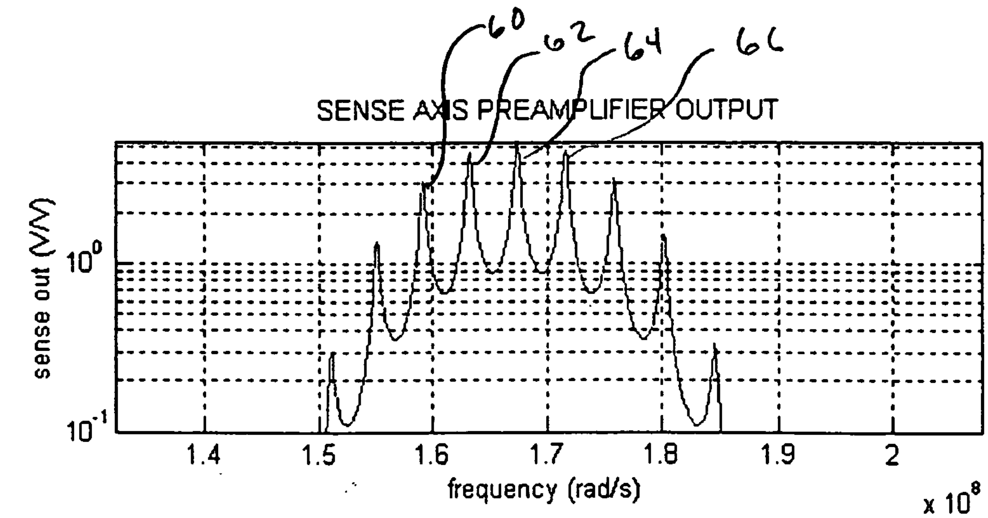

60
62
64
66
SENSE AXIS PREAMPLIFIER OUTPUT
sense out (V/V)
10^0
10^{-1}
1.4
1.5
1.6
1.7
1.8
1.9
2
frequency (rad/s)
x 10^8

Fig. 3A

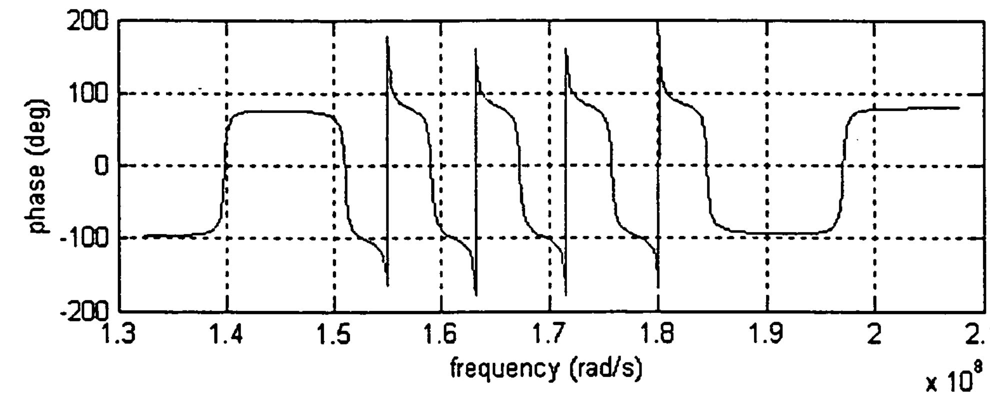

200
100
0
-100
-200
phase (deg)
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
frequency (rad/s)
x 10^8

Fig. 3B

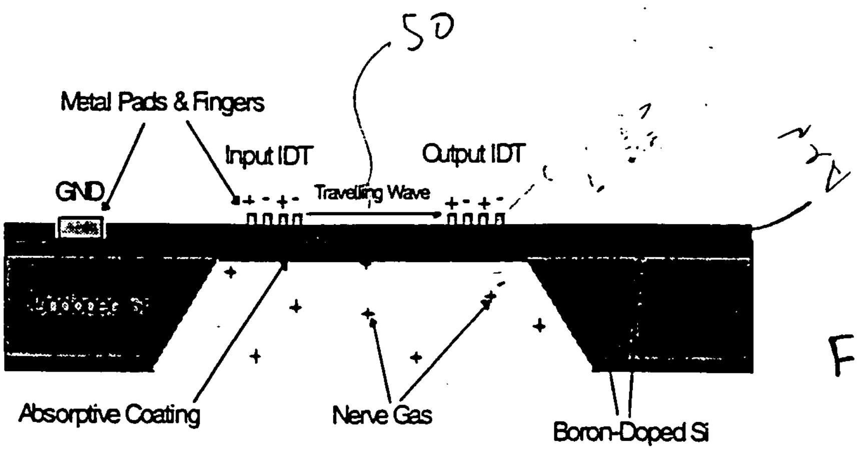


Fig. 4 (prior ART)

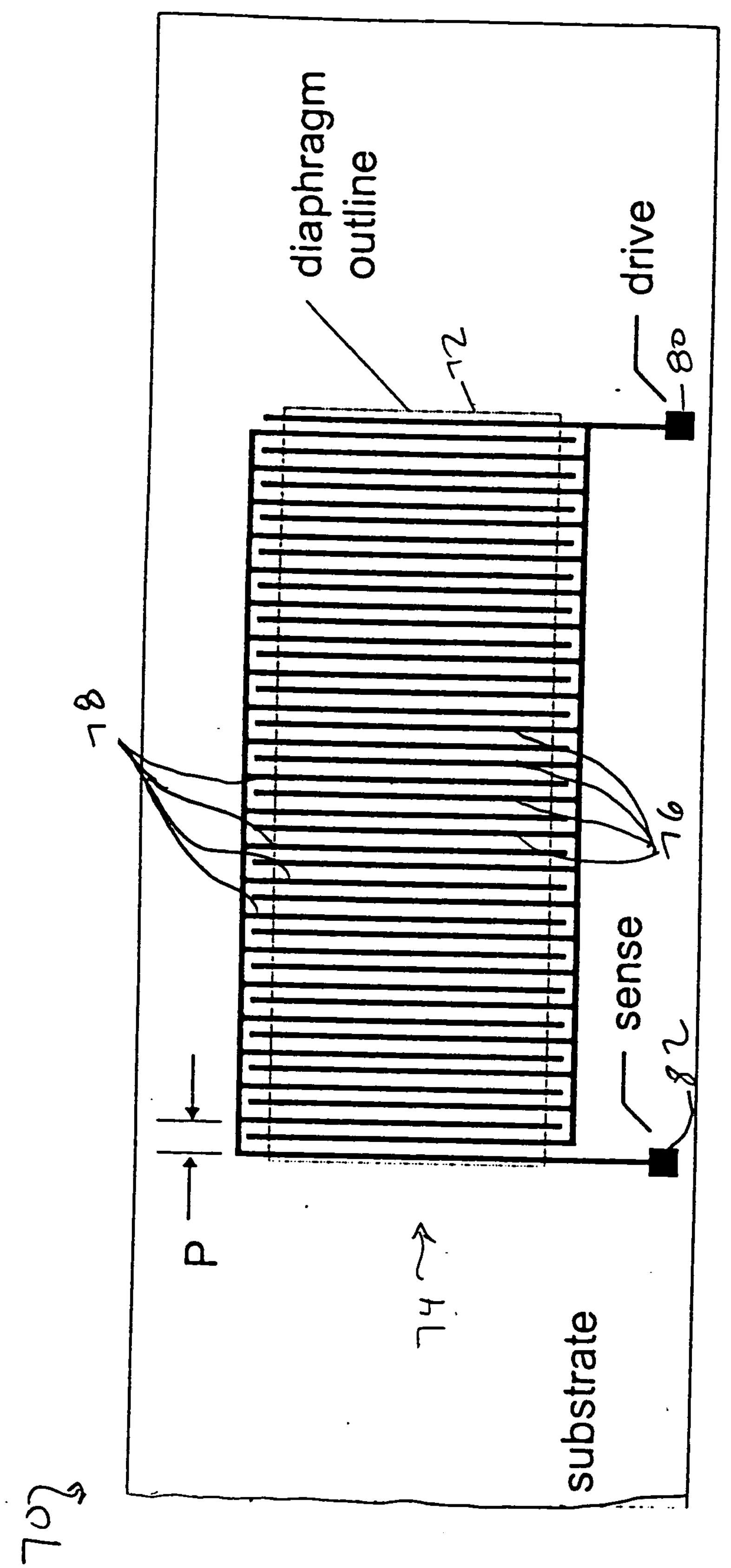

diaphragm outline
72
drive
80
78
76
sense
82
P
74
substrate
70

Fig. 5

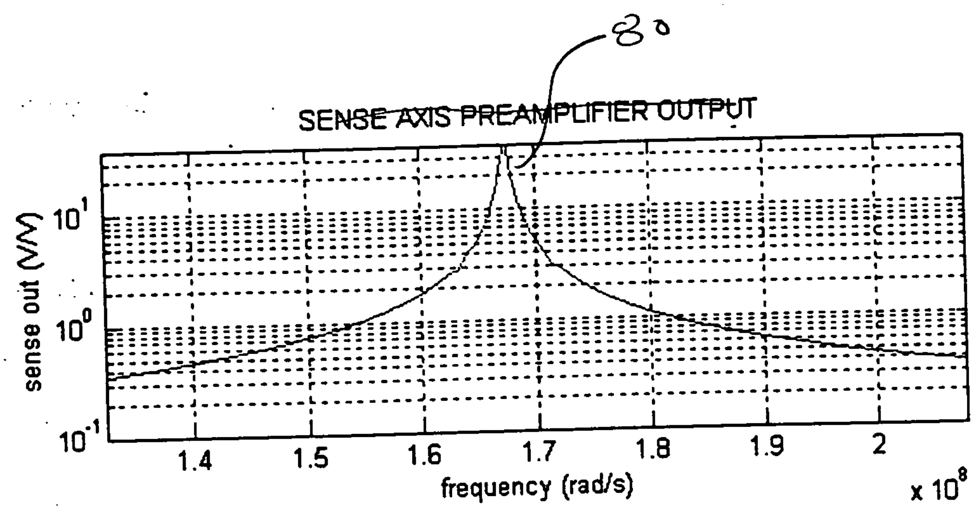

80
SENSE AXIS PREAMPLIFIER OUTPUT
sense out (V/V)
10^1
10^0
10^-1
1.4
1.5
1.6
1.7
1.8
1.9
2
frequency (rad/s)
x 10^8

Fig. 6A

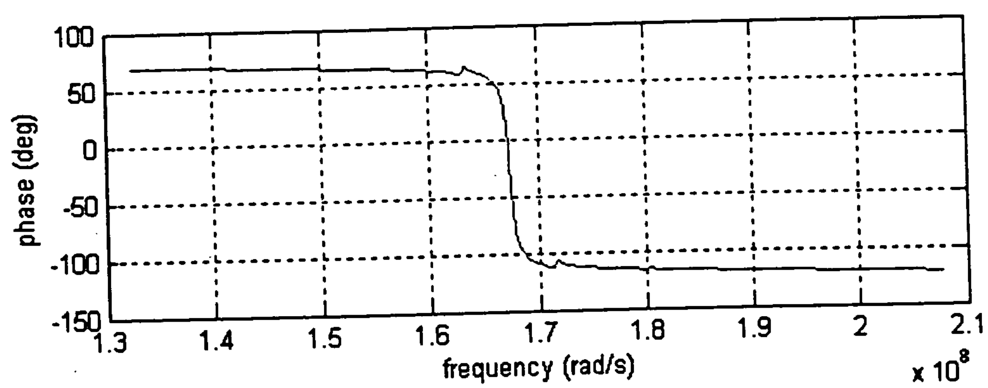

phase (deg)
100
50
0
-50
-100
-150
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
frequency (rad/s)
x 10^8

Fig. 6B

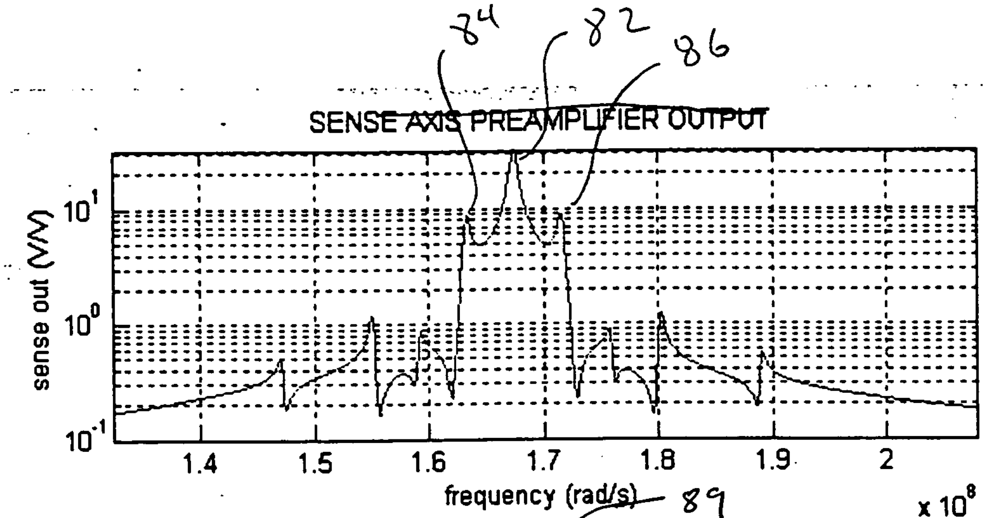

84
82
86
~~SENSE AXIS PREAMPLIFIER OUTPUT~~
sense out (V/V)
10^1
10^0
10^{-1}
1.4
1.5
1.6
1.7
1.8
1.9
2
frequency (rad/s)
x 10^8

Fig. 7A

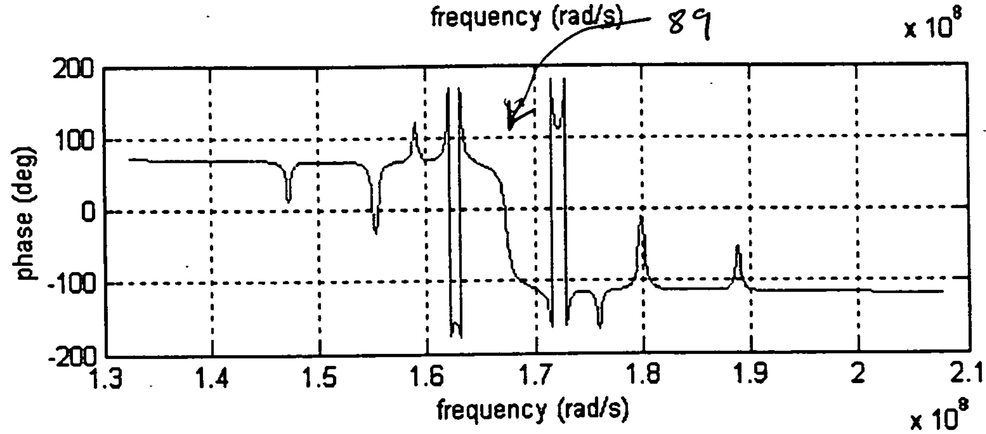

89
phase (deg)
200
100
0
-100
-200
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2
2.1
frequency (rad/s)
x 10^8

Fig. 7B

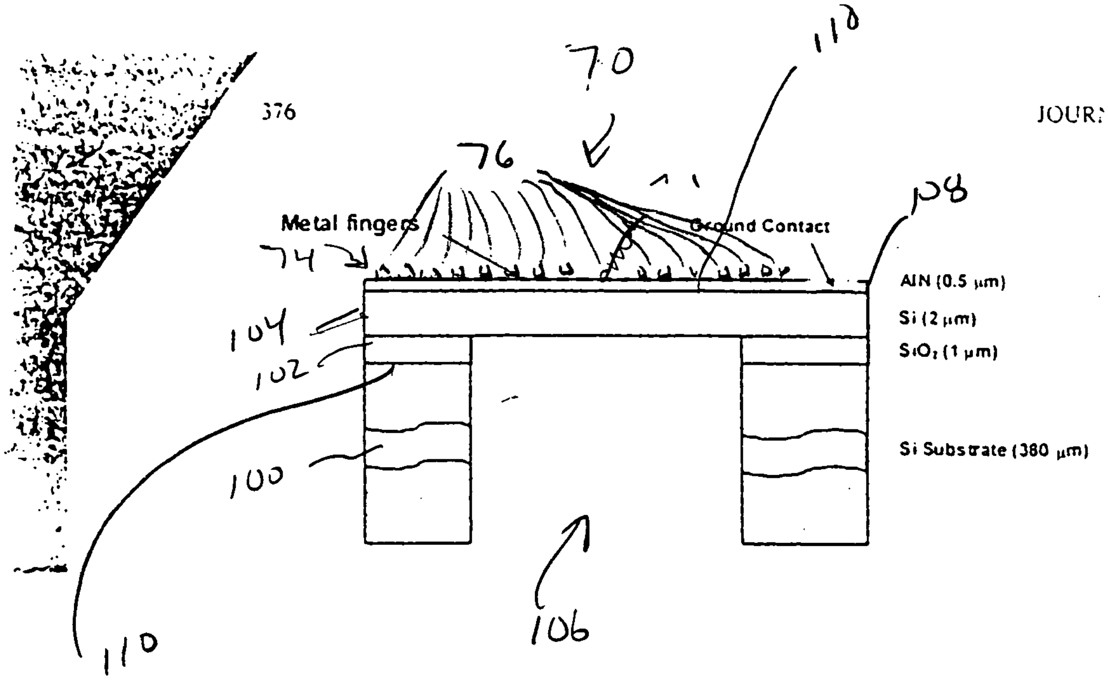

376
70
76
74
Metal fingers
Ground Contact
AlN (0.5 μm)
Si (2 μm)
SiO2 (1 μm)
Si Substrate (380 μm)
104
102
100
110
106
108

Fig. 8

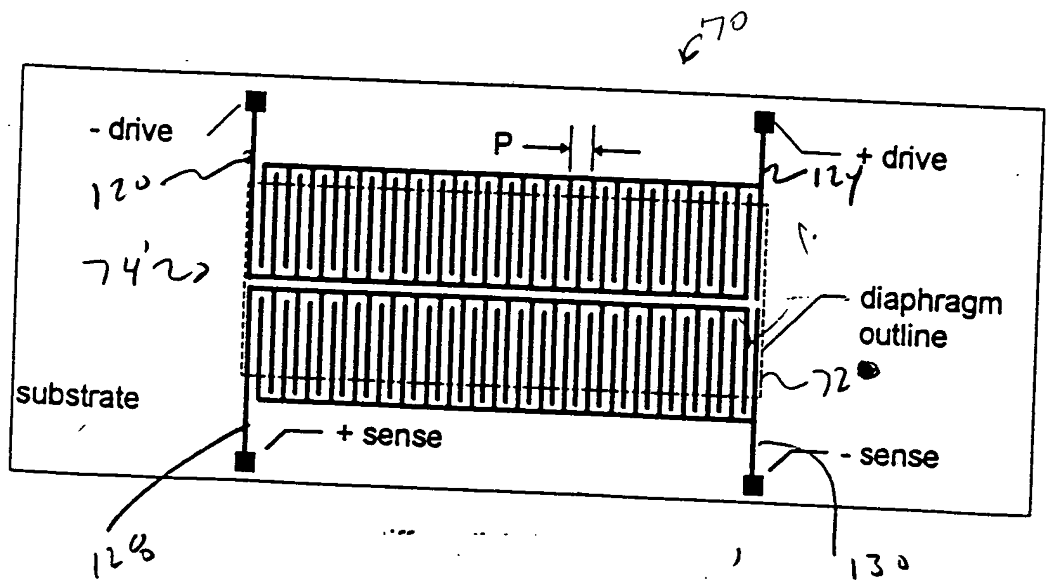
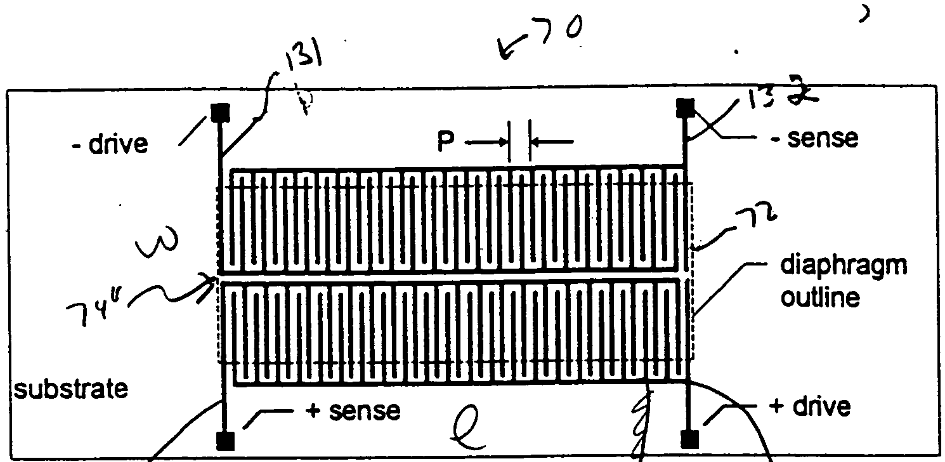

70
- drive
P
+ drive
120
124
74'
diaphragm
outline
72
substrate
+ sense
- sense
128
130

Fig. 9

DRAPER PROPRIETARY



1 Peak

Fig. 10

Design 4. Differential signals-interleaved

Figure 6. ~~Recommended design options (continued)~~

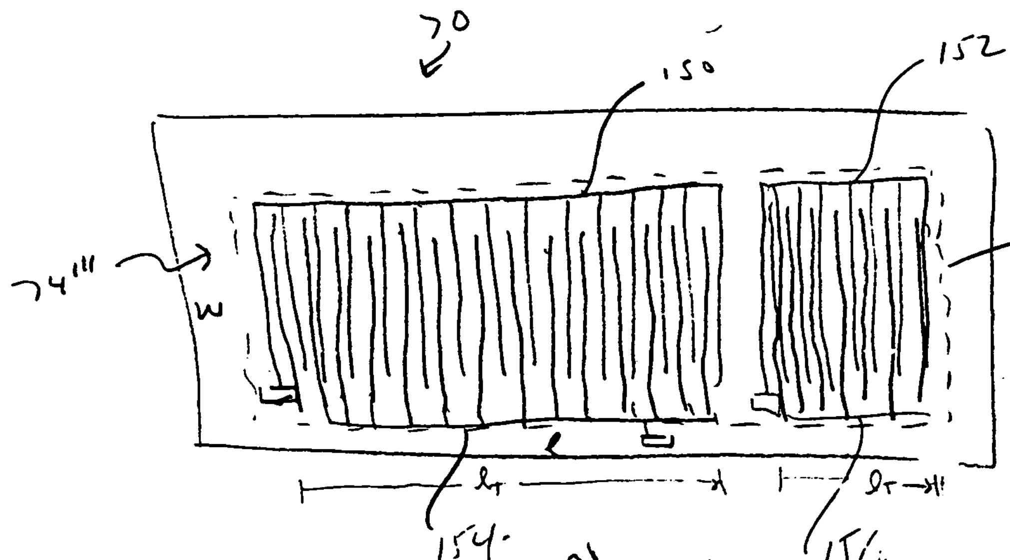


Fig. 11A

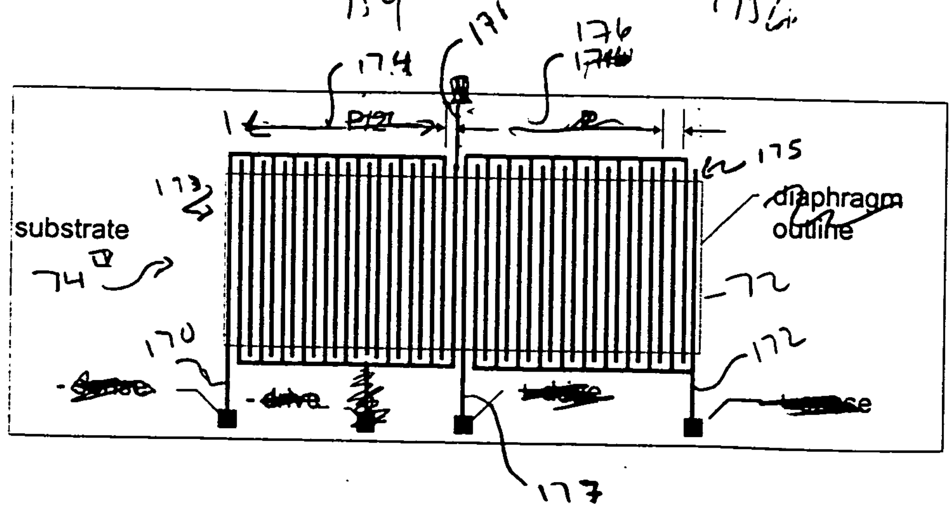


Fig. 11B

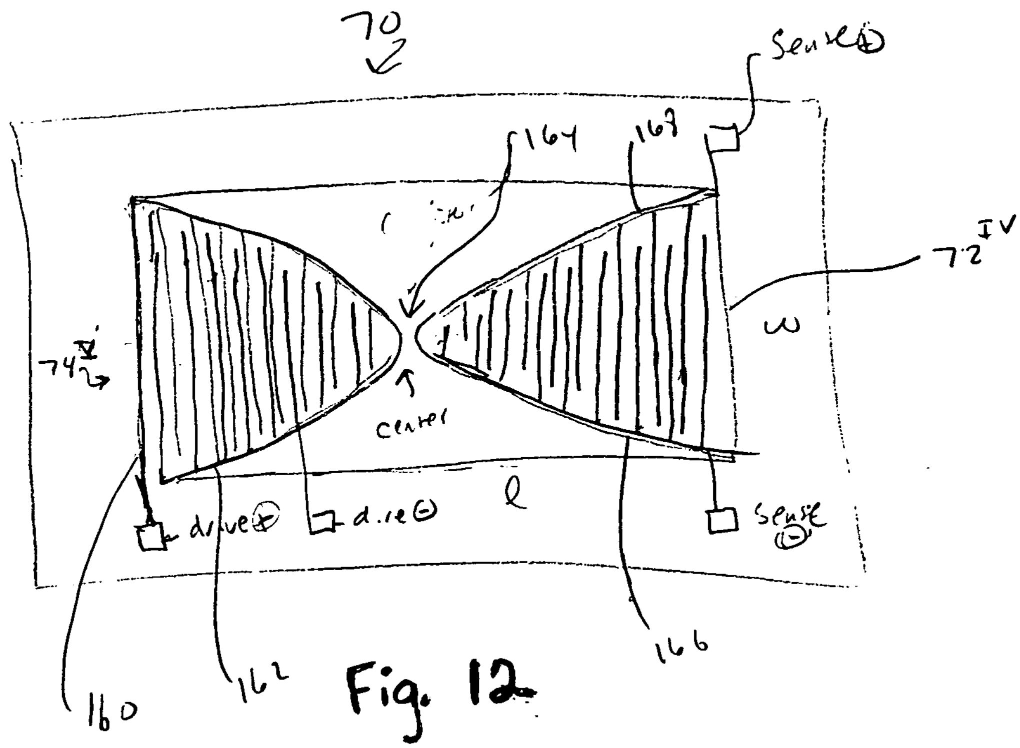

70
Sense(+)
164
168
72IV
w
74V
center
l
drive(+)
drive(-)
Sense(-)
160
162
166

Fig. 12

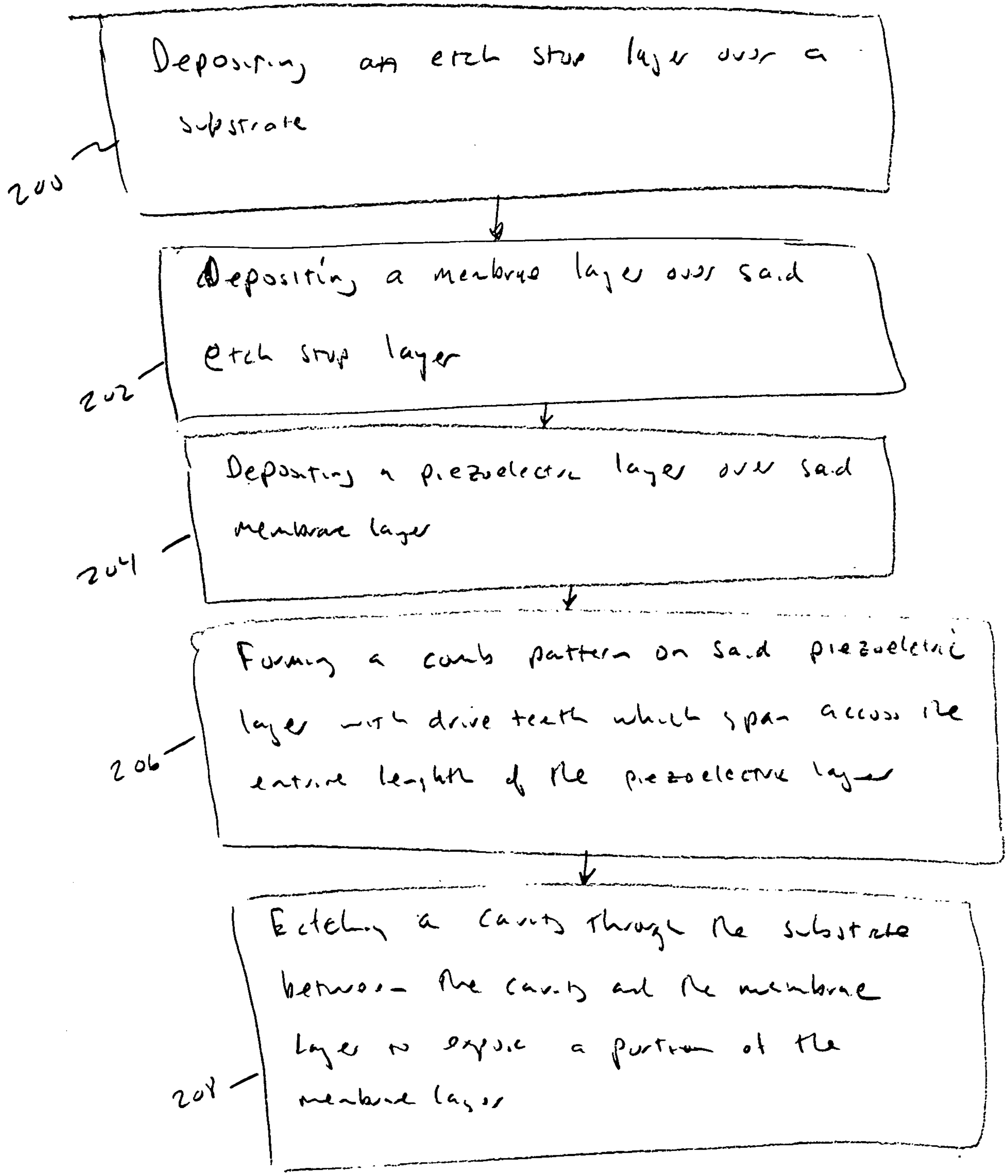

200
Depositing an etch stop layer over a substrate
202
Depositing a membrane layer over said etch stop layer
204
Depositing a piezoelectric layer over said membrane layer
206
Forming a comb pattern on said piezoelectric layer with drive teeth which span across the entire length of the piezoelectric layer
208
Etching a cavity through the substrate between the cavity and the membrane layer to expose a portion of the membrane layer

Fig. 13

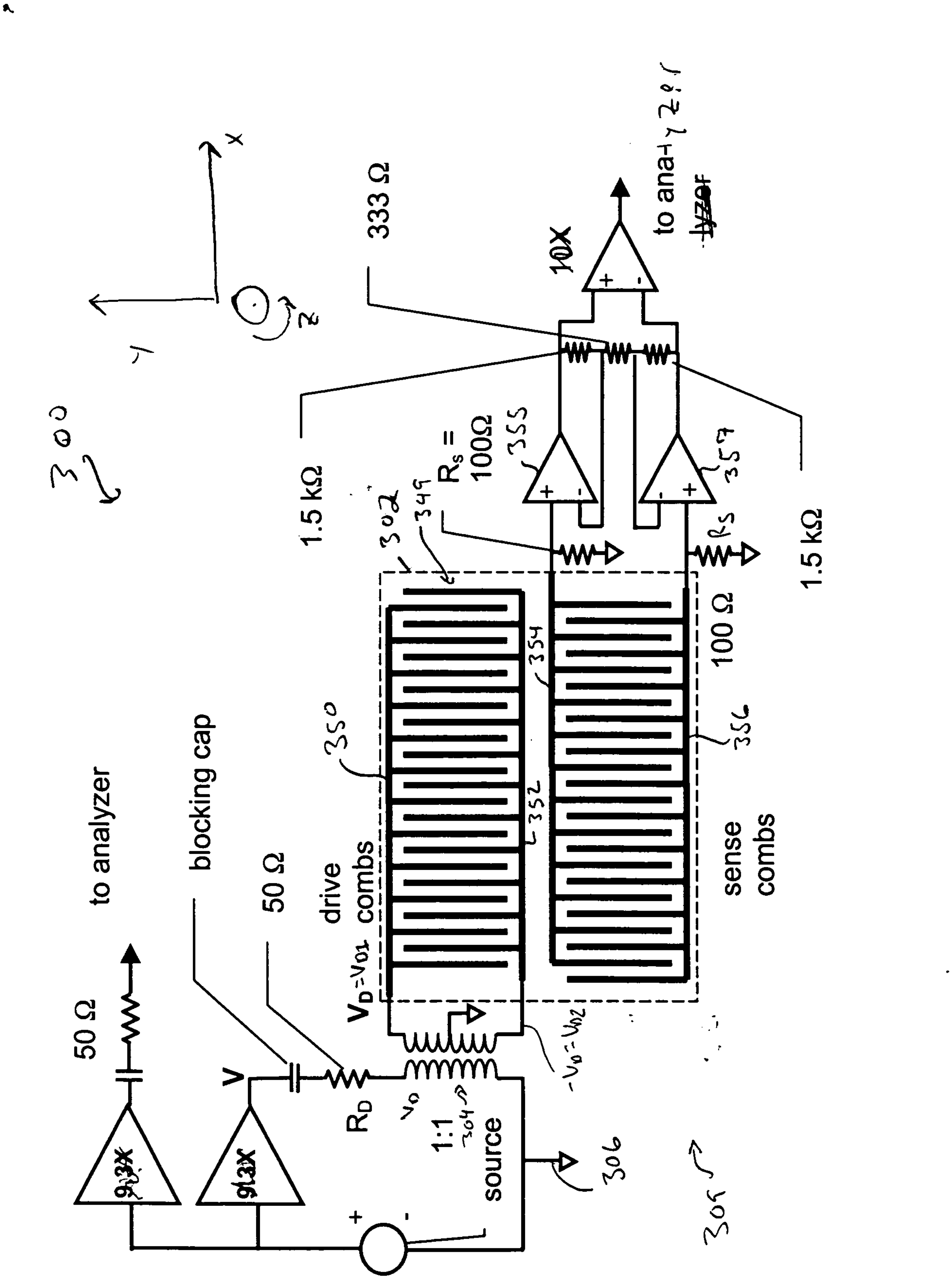

300
x
y
z
333 Ω
10X
to analyzer
1.5 kΩ
1.5 kΩ
R_s = 100Ω
355
357
R_s
302
349
100 Ω
354
352
350
356
drive combs
sense combs
to analyzer
blocking cap
50 Ω
50 Ω
V
$V_D = V_{D1}$
$-V_D = V_{D2}$
R_D
V_D
1:1
304
source
306
305
+
-

Fig. 14

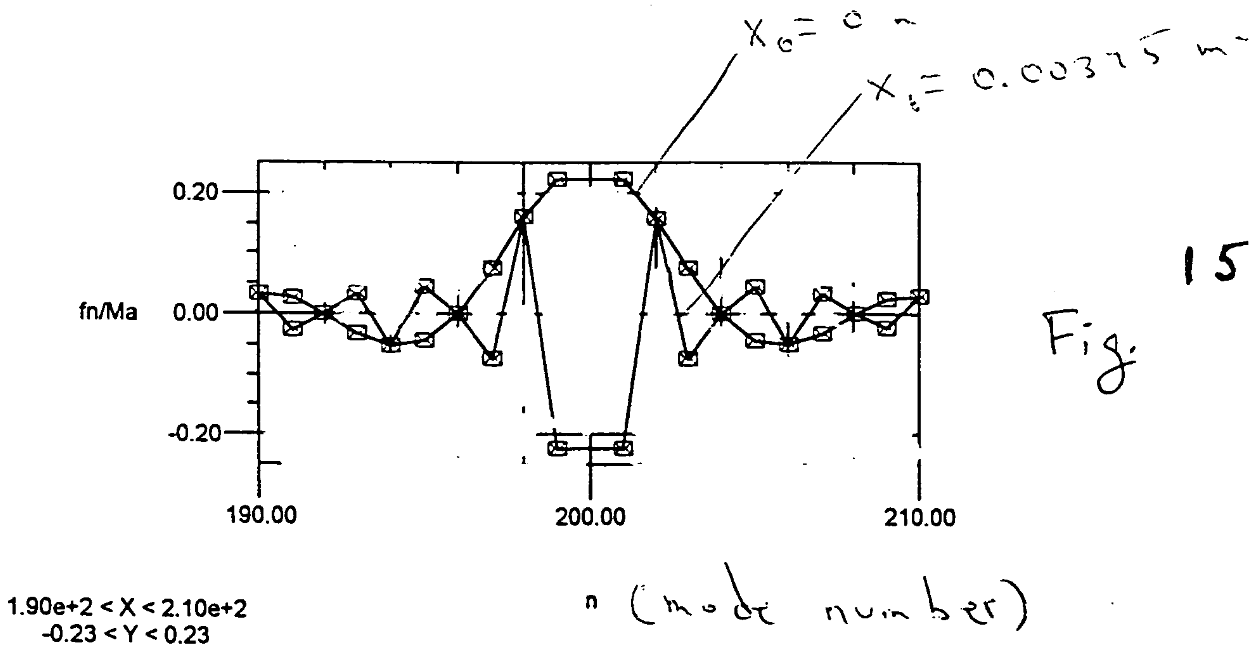


Fig. 15A

$\ell_T = 0.00125$

$\phi = 0$

$X_c = 0$

$X_c = 0.00375$ m

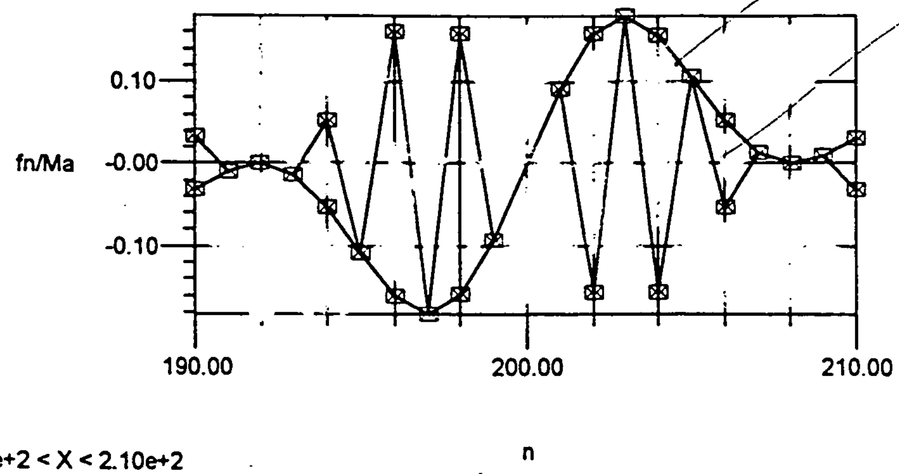


Fig. 15B

1.90e+2 < X < 2.10e+2
-0.18 < Y < 0.18

$\phi = \pi/2$

$X_c = 0$

$X_c = 0.00375$ m

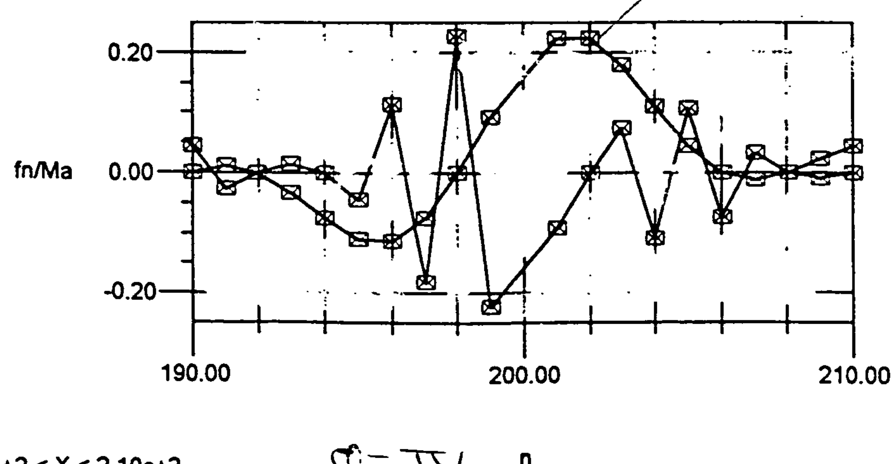


Fig. 15C

1.90e+2 < X < 2.10e+2
-0.23 < Y < 0.23

$\phi = \pi/4$

Fig. 16A

```
%MATLAB CODE FOR FPW CHEMICAL SENSOR MODAL FREQUENCY RESPONSE
%
%VARMODEEIG.M  PARAMETERS FOR MICROCANARY
%PLATE WAVE RESONATOR DYNAMIC MODEL
%BASED ON FPW5 EXPANDED TO ARBITRARY NUMBER OF MODES BY ELI WEINBERG 7/19/99
%SEPTEMBER, 1999. CLOSER SCALING AND DIFFERENTIAL SENSE READING ADDED BY MSW.
%SEPARATE DRIVE AND SENSE INPUTS
%FIRST CODED 10/13/97
%   9/20/02 Calculate eigenvalues (photosensitivity investigation) difference from mechanical o
nly
%LATEST RUN 9/20/02

% 11/13/01 ATTEMPT THE CHEMICAL SENSOR Q = 100 CASES
clear, format compact, format short e, i=sqrt(-1);
diary c:\matlab6p1\mw\varmodec.dia
rd = 50/4   %xxx
 %EXTERNAL DRIVE RESISTANCE.  THE FACTOR OF FOUR ACCOUNTS FOR THE N=2
 %TRANSFORMERS AND THE FACT THAT CD IS FOR +/- DRIVE IN PARALLEL.
rs = 100/2   %xxx  %ONE HALF EXTERNAL SENSE RESISTANCE (ohm)
  %THE FACTOR OF  TWO ACCOUNTS FOR CS IS +/- DRIVE IN PARALLEL.
  %GAINS BEFORE SOURCE VOLTAGE IS APPLIED TO FPW
gamp=1   %INPUT AMPLIFIER-BOTH INPUT AND REFERENCE LEGS HAVE SAME GAIN
ginst = 190  %INSTRUMENTATION AMPLIFIER GAIN-
%Completely differential amplifier with 10X second stage
gtran= 0.5    %TRANSFORMER GAIN
%VALUES FOR ALN = 0.5 MICRON, SI = TWO MICRONS
mp=2.47e-6  %xxx MASS PER UNIT LENGTH (KG/M)
dd = 8.781e-11  %STRUCTURAL RIGIDITY (N/M^2)
%q = 400 when bb = 1.033    %xxx                   %QUALITY FACTOR
bb = 1.033                 % xxx damping (N-s/m^2)
l = 0.0015        %LENGTH OF DIAPHRAGM (m)
ld = 3.750001E-5*19   %LENGTH OF THE DRIVE TRANSDUCER
ls = 3.750001E-5*19   %LENGTH OF THE SENSE TRANSDUCER
md=38                 %NUMBER OF HALF PERIODS IN TRANSDUCER
ms=38                 %NUMBER OF HALF PERIODS IN TRANSDUCER
pd = 2*ld/md          %PITCH OF DRIVE FINGERS (M)
```

Fig. 16 B

```
ps = 2*ls/ms          %PITCH OF SENSE FINGERS (M)
%CALCULATE THE MODAL FORCING FUNCTION
phi= 0         %PHASE OF EIGENFREQUENCY (0 FOR PINNED, PI/4 FOR BUILT-IN)
thetad= 0      %PHASE OF TRANSDUCER (radians)
thetas = 0
xd=0         %STARTING POSITION FOR FORCING COMBS
xs=l-ls-xd          %STARTING POSITION OF TRANSDUCER 20
%BEWARE CHANGING XD TO ADJUST TOLERANCES.
%SCALE FACTOR FOR LENGTH OF SENDER OR RECEIVER COMB
%MODEINT IS MSW FUNCTION BASED ON MACSYMA INTEGRATION

nmode=input('Enter number of modes  ')
model=input('Enter number of first mode in model  ')

for c0=1:nmode
   n(c0)=(model-1+c0);
end  %MODE NUMBER, ROUGHLY NUMBER OF HALF WAVE LENGTHS



alph = 0.004874/1.676e5^2
      %piezo coupling coefficient for 100% transducer length (coul/m)
gamm = 9.39e-11*1.676e5^4            %piezo coupling coefficient (m/V)

for c1 = 1:nmode;
    pc(c1,1)=modeint(n(c1),md,l,ld,phi,thetad,xd);
    pc(c1,2)=modeint(n(c1),ms,l,ls,phi,thetas,xs);
    lam(c1)=n(c1)*pi/l; %eigenvalue of plate motion (1/m)
    gammad(c1)=gamm*pc(c1,1)/lam(c1)^4;
    gammas(c1)=gamm*pc(c1,2)/lam(c1)^4;
    alphad(c1)=alph*lam(c1)^2*pc(c1,1);
    alphas(c1)=alph*lam(c1)^2*pc(c1,2);
    wn(c1)=sqrt(dd/mp)*lam(c1)^2;  %eigenfrequency (rad/s)
    damping(c1) = bb;           %mode damping (N-s/m^2)
    k(c1) = mp*wn(c1)^2;            %mode stiffness (N/m^2)
    checkalpha(c1) = 1-gammad(c1)*k(c1)*0.5*l/alphad(c1);
```

19 C

Fig. 16 C

```
end
pc,wn,gammad,gammas,alphad,alphas,checkalpha

cs = 7.567e-11*ls/l   %CAPACITANCE FROM SENSE COMBS TO GROUND, 2 POLES (F)
                %EQUAL TO THAT CALCULATED IN TABLE 1. STRAYS MAY ADD MORE.
cd = 7.567e-11*ld/l                      %DRIVE CAPACITANCE (F)
rfb=rs*ginst           %SENSE AXIS RESISTOR AND INSTRUMENTATION AMPLIFIER

%ENTER THE COEFFICIENTS OF THE DERIVATIVES
%STATES ARE [QD,QS,V1,X1,V2,X2,V3,X3]
ml=zeros(2+2*nmode, 2+2*nmode);
mra=zeros(2+2*nmode, 2+2*nmode);
ml(1,1)=(cd*rd);
ml(2,2)=cs*rs;
mra(1,1)=-1;
mra(2,2)=-1;

for c2=1:nmode
   ml(2*c2+1, 2*c2+1)=mp;
   ml(2*c2+2, 2*c2+2)=1;
   ml(2*c2+1, 1)=rd*k(c2)*gammad(c2);
   ml(2*c2+1, 2)=rs*k(c2)*gammas(c2);

   mra(2*c2+1, 2*c2+1)=-damping(c2);
   mra(2*c2+1, 2*c2+2)=-k(c2);
   mra(2*c2+2, 2*c2+1)=1;
   mra(1, 2*c2+2)=alphad(c2);
   mra(2, 2*c2+2)=alphas(c2);
end

%ENTER COEFFICIENTS OF DRIVE VOLTAGE
mrb=zeros(2*nmode+2, 1);
mrb(1)=cd;
for c3=1:nmode
   mrb(2*c3+1)=k(c3)*gammad(c3);
end
```

Fig. 16D

```
%ml,mra,mrb

%SET UP THE STATE MATRICES
invml=inv(ml);
checkinvml=invml*ml
a=invml*mra
b=invml*mrb
[evec,eval]=eig(a);
damp(eval)
%eval
%evec

%PICK OUT THE DIFFERENCE IN THE EIGENFREQUENCIES
yy=sort(damp(eval));  %PLACE THE EIGENVALUES IN ORDER. CHECK THAT THE POLES CORRESPONDING TO THE
                      %RC ARE HIGHER THAN THE MECHANICAL POLES
for ii = 1:nmode
    wncl(ii)=yy(2*ii-1);  %MAKE THE VECTORS OF DIFFERENT LENGTHS SIMILAR AND OMIT THE TWO FASTEST POLES
end
wndiff=wncl-wn      %SHIFT FROM MECHANICAL RESONANCES TO CLOSED LOOP

%OUTPUTS ARE AMPLITUDE,SENSE PREAMPLIFIER OUTPUT, AND INPUT CHARGE THROUGH RD
%WITH GIN = 1 INPUT IS INPUT TO 10X AMPLIFIER WHICH IS MEASURED BY
%ANALYZER
gin = 1   %SOURCE TO PREAMP INPUT
c=zeros(3, 2+2*nmode);
for c4=1:nmode
   c(1, 2*c4+2)=1;
   c(2, :)=a(2, :)*rfb;
   c(3, 1)=.5;
   end
c=c*gamp*gtran*gin
d=[0;b(2,:)*rfb; 0]*gamp*gtran*gin
%w=logspace(7,9,200);
```

19 E

Fig. 16 E

```
nw=1001
dw=(1.1*wn(nmode)-0.9*wn(1))/(nw-1);
w=[0.9*wn(1):dw:1.1*wn(nmode)];
wmax=w(length(w))
[m1,p1]=unbode(a,b,c,d,1,w);
xmax = max(m1(:,1))
vmax = max(m1(:,2))
figure(1),clf,subplot(2,1,1)
semilogy(w,m1(:,2)),grid,xlabel('frequency (rad/s)')
ylabel('sense out (V/V)'),axis([w(1),wmax,0.01,max(m1(:,2))])
title('SENSE AXIS PREAMPLIFIER OUTPUT')
subplot(2,1,2)
plot(w,p1(:,2)),grid,xlabel('frequency (rad/s)'), ylabel('phase (deg)')
figure(2),clf,subplot(2,1,1)
semilogy(w,m1(:,1)),grid,xlabel('frequency (rad/s)')
ylabel('amplitude (m/V)'),axis([w(1),wmax,0.01*max(m1(:,1)),max(m1(:,1))])
title('MOTION AMPLITUDE')
subplot(2,1,2)
plot(w,p1(:,1)),grid,xlabel('frequency (rad/s)'), ylabel('phase (deg)')
figure(3),clf,subplot(2,1,1)
semilogy(w,m1(:,3)),grid,xlabel('frequency (rad/s)')
ylabel('charge (C/V)')
title('DRIVE CHARGE')
subplot(2,1,2)
plot(w,p1(:,3)),grid,xlabel('frequency (rad/s)'), ylabel('phase (deg)')
%[z,p,k]=ss2zp(a,b,c,d,1) %OBTAIN THE POLES AND ZEROS OF TRANSFER FUNCTION
diary off
```

19F_mw

Fig. 16F

```
function [pc]=modeint(n,m,l,lt,phi,theta,xo);
%FUNCTION TO OBTAIN THE MODAL FORCING FUNCTION NORMALIZED TO ONE
%DERIVED BY MACSYMA AND CODED 10/20/97
pc  = -lt*sin(((pi*lt*n+pi*l*m)*xo-l*lt*theta-l*lt*phi+pi*lt^2....
        *n+pi*l*lt*m)/(l*lt))/(pi*(lt*n+l*m))+lt*sin(((pi*lt*n+.....
        pi*l*m)*xo-l*lt*theta-l*lt*phi)/(l*lt))/(pi*(lt*n+l*m))+lt*....
        sin(((pi*lt*n-pi*l*m)*xo+l*lt*theta-l*lt*phi+pi*lt^2*n-pi.....
        *l*lt*m)/(l*lt))/(pi*(lt*n-l*m))-lt*sin(((pi*lt*n-pi*l*m)*......
        xo+l*lt*theta-l*lt*phi)/(l*lt))/(pi*(lt*n-l*m));

```

DRAPER PROPRIETARY

RELATIVE EIGENFREQUENCIES FOR PLATES

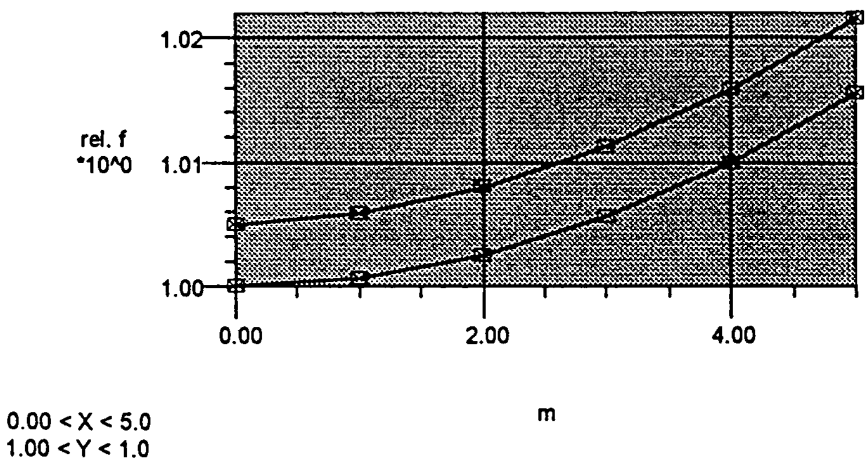


Fig. 17

a. $\ell/b = 5$

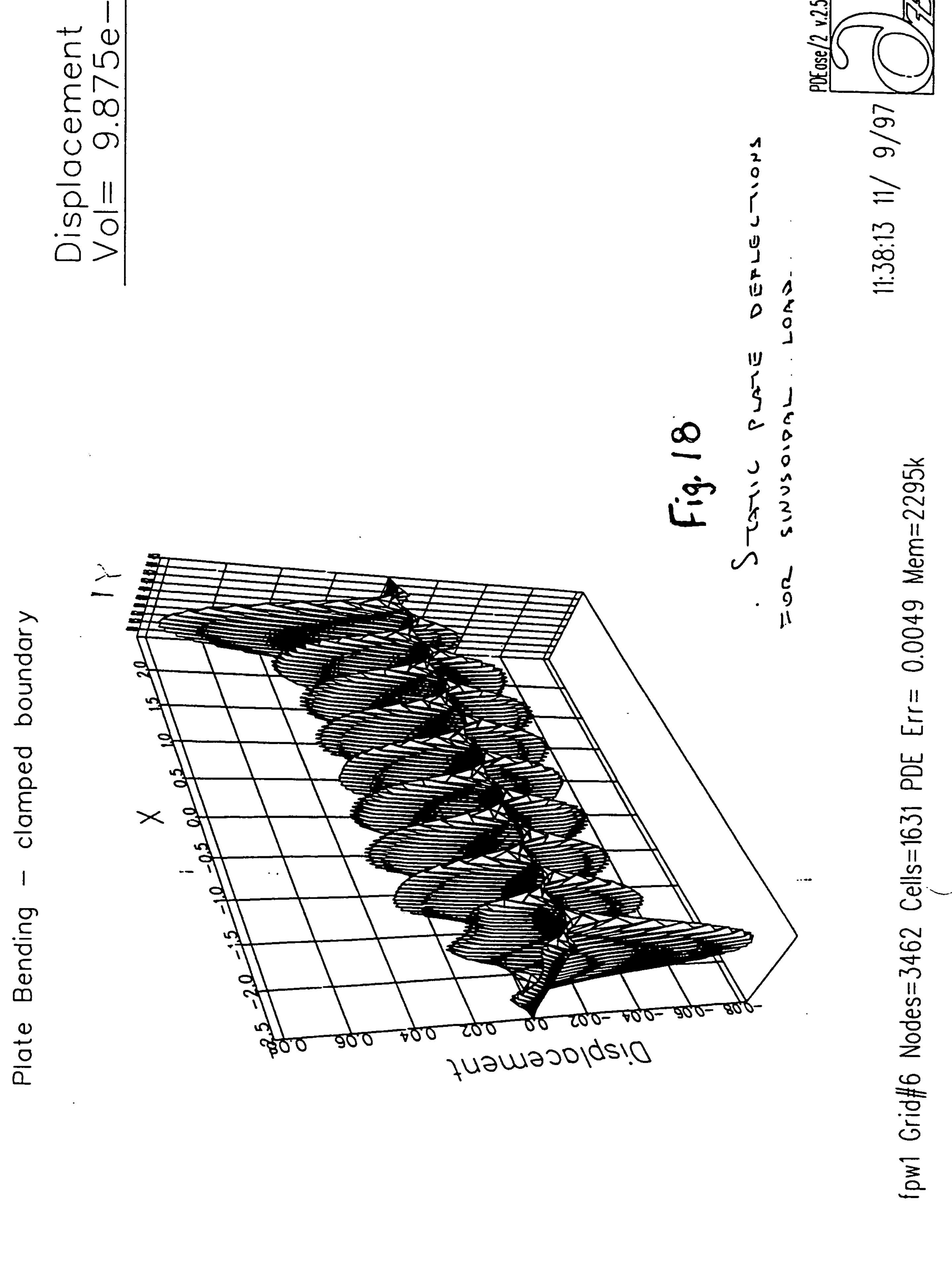


Fig. 18
STATIC PLATE DEFLECTIONS FOR SINUSOIDAL LOAD.